Exploring Entrepreneurial Learning: A Comparative Study of Technology Development Projects**[1]**

Davide Ravasi[a], Carlo Turati[b]

[a]*Università Commerciale L. Bocconi, Milan, Italy*
[b]*Università di Lecce, Lecce, Italy*

Abstract

In this paper, we report findings from a comparative study of factors that influence the learning process that underlies entrepreneurial innovation, as entrepreneurs move from an initial intuition to a well-developed new product or service. Evidence from our comparative study highlights the self-reinforcing effect of prior related knowledge, perceived incentives and the degree of control on the allocation of entrepreneurs' limited time, attention and resources. Combining theory and evidence from our study, we propose an interpretative model that suggests that innovation in entrepreneurial ventures rests on self-reinforcing learning cycles that lead entrepreneurs to dedicate increasing resources to the exploration of some opportunities at the expense of others, following a sensemaking process affected by their previous knowledge and their degree of involvement in the projects.

1. Executive Summary

Most literature on entrepreneurship emphasizes the discovery of opportunities and the decision to exploit them as the essence of entrepreneurial action. Entrepreneurs are usually depicted as sagacious pursuer of opportunities and bold risk takers. This representation, however, neglects a fundamental learning process, which takes place as entrepreneurs develop an initial intuition into a successful new product or service. Successful entrepreneurial innovation, in fact, requires more than the capacity to discern an opportunity for entrepreneurial profit and the willingness to accept the associated risk. Entrepreneurs often deal with new and ill-defined product concepts, whose context of use is still poorly understood and whose commercial applications are not fully explored yet. Many business opportunities appear in very rough intuitive form, and require a search for additional information before their feasibility and profitability can be reasonably assessed. Between the recognition of an opportunity and its successful exploitation, lies a critical, albeit often underestimated, learning process that takes place as entrepreneurs gradually manage to make sense of the connections between the different technologies, product functions, customers' preferences, market structure, etc.

While learning is intrinsic to any type of innovation, learning in entrepreneurial ventures usually takes place in particularly adverse conditions. First, entrepreneurs tend to face a high degree of ambiguity, as they search for solutions for problems that are still imperfectly defined, as they explore applications of new technologies that are not fully developed, and as they take guesses about which opportunities are worth pursuing. Second, the development of entrepreneurial ideas requires contributions of a different nature from a range of actors, whose knowledge and skills are complementary to the entrepreneurs'. Typically, entrepreneurs possess a good knowledge of the market and the customers, and often a certain degree of technical competence in his field. However, the actual realization of their ideas often requires not only financial resources, but also skills and competencies that must be obtained from industrial, commercial and research partners, consultants, designers, etc. Finally, entrepreneurial ventures tend to suffer from a relatively high scarcity of money, time and attention. These constraints affect entrepreneurial learning, imposing periodic choices about the continuation or the termination of developmental efforts.

Our research explores how these constraints affect the learning process of entrepreneurs engaged in developmental efforts. Evidence from our study suggests that success and failure of entrepreneurial innovation may be affected by virtuous (or vicious) circles, which may bring entrepreneurs to dedicate more and more time, attention and resources to some projects at the expense of others. A solid related knowledge base and a deep involvement in all the activities where critical learning takes place are fundamental in reinforcing the capacity to play a pivotal role and to assess the potential "return on the learning investment" – i.e. the expected commercial return of the time and resources dedicated to the project. In absence of a related knowledge base, entrepreneurs may eventually be forced to abdicate their leading role in the development process, and gradually lose the capacity to assess the levels of risk and return associated to the completion of the project. In this respect, our findings seem to discourage from initiating explorative venture whose technological platforms are distant from the entrepreneurs' core technological and scientific domains.

In summary, mastering the critical knowledge platforms required for the successful development of the new product or service affects learning in entrepreneurial innovation as (i) it allows entrepreneurs to preserve a leading role in coordinating collective contributions, (ii) it improves the entrepreneurs' capacity to make sense of the tasks ahead, and therefore it increases their control over the process, (iii) it facilitates an assessment of the potential risk and return associated with the initiative, (iv) it prevents a loss of confidence, due to personal rather than objective reasons, and (v) it helps capture newly created knowledge, further upgrading the knowledge base of the entrepreneurs.

2. Introduction

Research on learning processes in entrepreneurial ventures is still in an early stage (Agnedal, 1999; Minniti and Bygrave, 2001). Although the importance of learning processes in discriminating successful ventures from unsuccessful ones is widely acknowledged (e.g. Ireland, Hitt, Camp and Sexton, 2001; Nicholls-Nixon, Cooper and Woo, 2000), empirical studies are still rare. Past studies of entrepreneurial cognition tended to focus on issues such as risk taking (i.e. Brockhaus, 1980; Begley and Boyd, 1987; Brockhaus and Horowitz, 1986; Simon, Houghton and Savelli, 2003) or opportunity recognition (i.e. Palich and Bagby, 1995; Shane, 2000). The learning processes that occur as entrepreneurs accumulate and organize knowledge and information within (i.e. Van de Ven and Polley, 1992; McGrath, 1995) and across developmental efforts (Minniti and Bygrave, 2001), however, are still underexplored phenomena.

From a cognitive point of view, entrepreneurial innovation can be conceived as a process of building and refining a set of knowledge structures – technologies, routines, interpretations etc. – that transform an initial intuition into a viable new product or service, a new production process or a new way to serve the market (Schumpeter, 1934). In this paper, we investigate the learning process that underlies the successful generation and integration of knowledge in entrepreneurial ventures, as new combinations of resources are being explored and the potential risk and returns of the venture are gradually made sense of (Van de Ven and Polley, 1992).

A review of past research indicates that three contextual conditions may affect learning in entrepreneurial ventures. First, although the exploitation of existing resources and the optimization of current combinations are essential for the long-term prosperity of the firm, what is central to entrepreneurial action is the exploration of new possibilities, the experimentation of new ideas (Schumpeter, 1936). As such, entrepreneurs usually face a high degree of ambiguity, conceived as imperfect knowledge of the connection between means and ends (Garud and Van de Ven, 1992). Second, entrepreneurs tend to pursue business opportunities regardless of the resources they actually control (Stevenson and Gumpert, 1985). The development of entrepreneurial ideas often requires contributions of a different nature from a range of actors, whose knowledge and skills are complementary to the entrepreneurs' (Aldrich and Zimmer, 1986; Birley, 1985; Larson, 1991). This means also that entrepreneurs may need to rely on external assistance as they evaluate the feasibility and profitability of a business opportunity. Finally, entrepreneurial ventures tend to suffer from a relatively high scarcity of resources, related not only to the small stock of financial and physical resources on which the venture relies (Kirchoff, 1994; Garnsey, 1998), but also to the limits to the time available to and the attention span of the entrepreneur (Garud and Van de Ven, 1992; Gifford, 1998). Consequently, entrepreneurs may periodically be required to decide what opportunities are worth exploring and whether certain development projects should be continued or terminated. Investigation of entrepreneurial learning, therefore, should at least partially account for how ambiguity, outside assistance and shortage of resources affect the process as entrepreneurs move from an initial intuition to a well-developed and integrated set of knowledge structures that constitute and support a new product or service.

Our research relied on a comparative analysis of two technology-development projects – one successful and one unsuccessful – run by the same entrepreneur at about the same time. The adoption of a rich, qualitative method for data collection and analysis was justified by the exploratory nature of the study (Yin, 1989; Lee, 1998), and by the focus on the learning process that underlies successful innovation (Van de Ven and Polley, 1992; Miner and Mezias, 1996). Evidence from our study highlights the self-reinforcing effect of prior related knowledge, perceived incentives and the degree of control on the process on the commitment of the entrepreneur and on the consequent allocation of time, attention and resources.

We believe that the contribution of our paper is threefold. First, our paper presents first evidence of some conditions that affect the successful development and refinement of knowledge in developmental efforts. A rich description and a longitudinal analysis helped us uncover a number of variables and produce an explanatory framework that may be later subjected to empirical test. Second, our interpretative model addresses a fundamental issue in an entrepreneurial setting: the need to distribute time and attention between different opportunities and different projects. Our model suggests that these decisions are affected by self-reinforcing learning processes that lead entrepreneurs to dedicate increasing time and attention to the exploration of some opportunities at the expense of others, following a gradual sense-making process that rests on entrepreneurs' previous knowledge and involvement in the projects. Finally, as the emerging conceptual framework addresses the issue of resource allocation between alternative projects, it can be extended to a more general case of management of multiple development projects (Burgelman, 1991) and internal corporate venturing (Bower, 1970; Garud and Van de Ven, 1992; Block and MacMillan, 1993). In this respect, our findings reinforce and extend Van de Ven and Polley's (1992) findings indicating the impact of resource availability and perceived likelihood of success in the decision to continue or terminate a corporate venture.

The paper is composed of six sections. In the first section, we discuss the distinctive features of learning in an entrepreneurial context. Next, we present the research site and we discuss our methodology. In the third section, we provide a general description of the two projects. In the following sections, we discuss insights emerging from the comparison of the projects. Building on past literature and evidence from our study, by weaving together variables resulting from the comparison, we develop a model of learning in entrepreneurial ventures. Implications for research and practice are discussed in the final section.

3. The learning context in entrepreneurial ventures

A recent review of past studies on learning among entrepreneurs concludes that, despite the importance of the issue, research is still at a preliminary stage (Agnedal, 1999). In a recent theoretical contribution, commenting on Kirzner's (1973) insightful observation that the purposeful search for information that follows the discovery of an opportunity is central to entrepreneurial activity, Bygrave and Minniti conclude that "entrepreneurship is a process of learning, and a theory of entrepreneurship requires a theory of learning (Minniti and Bygrave, 2001, p. 7)." Nevertheless, with some exceptions (i.e. Bailey, 1986; Guth, Kumaraswamy and McErlean, 1991) researchers in the field of entrepreneurship have devoted little attention to study how entrepreneurs learn.

Traditionally, research on the psychology of entrepreneurs focused on the cognitive traits, such as risk propensity, need for achievement, and self-confidence, that differentiate entrepreneurs from non-entrepreneurs (e.g. Begley and Boyd, 1987; Brockhaus, 1980; McClelland, 1961; Shaver and Scott, 1991; Forlani and Mullins, 2000). Empirical studies aimed at demonstrating the peculiarity of entrepreneurs' psychological traits, however, seem to have failed to produce conclusive results (Brockhaus and Horowitz, 1986; Low and McMillan, 1988). More recently, a number of studies shifted attention to the cognitive processes and mechanisms according to which entrepreneurs select and process information, to make sense of the external environment (Baron, 1998; Nicholls-Nixon, Cooper and Woo, 2000; Shane and Venkataraman, 2000). Drawing on cognitive schema theory, Palich and Bagby (1995) observed that entrepreneurs tend to frame opportunities in a more favorable way than non-entrepreneurs do. When facing an uncertain business situation, in fact, entrepreneurs seem to emphasize strengths and potential for gain, whereas non-entrepreneurs tend to stress weaknesses and potential for loss. Busenitz and Barney (1997) compared the way entrepreneurs and managers make decisions, and found that entrepreneurs' tend to use heuristics – simple decision rules that reduce the complexity of decision processes – more extensively than managers do. The two authors speculate that these cognitive biases may be beneficial insofar as they let entrepreneurs catch windows of opportunity even when time constraints do not allow a thorough and rational analysis. Finally, Shane's (2000) study of different market applications of the same invention supports the argument that opportunity recognition is driven more by the distinctive knowledge possessed by individuals, rather than by their personality traits. This idiosyncratic information allows people to discover opportunities that others cannot see, even if they are not actively searching for them (Hayek, 1945; Kirzner, 1997).

A distinctive feature of many studies on entrepreneurial cognition – be it related to opportunity recognition, risk taking or other – seems to be the assumption that what makes entrepreneurs different is either a set of psychological traits, or the way they collect, select and process information. Recent theoretical modeling of entrepreneurial learning seems to follow the same approach. Agndal's research agenda for studying learning among entrepreneurs, for instance, concentrates on individual learning styles (Bailey, 1986), implicitly assuming the existence of a fundamental difference between entrepreneurs and non-entrepreneurs. Minniti and Bygrave's dynamic model of entrepreneurial learning proposes a representation of the way entrepreneurs modify their courses of action over time, on the basis of their experience (Minniti and Bygrave, 2001). In other words, studying entrepreneurial learning has generally been conceived as investigating the unique and distinctive way in which entrepreneurs acquire, store and use knowledge (Agndal, 1999; Minniti and Bygrave, 2001).

Our research was based on a different assumption. Following a rising approach in research on entrepreneurial cognition (e.g. Baron, 1998), we expanded the scope of analysis from individual traits to the context within which entrepreneurial learning takes place. A review of past research on entrepreneurship led us to the identification of three distinctive features of learning in entrepreneurial ventures, namely the exploratory nature of the process, the reliance on external contributions, and the relatively high scarcity of resources available.

Ambiguity and exploration

Dealing with an ambiguous environment is intrinsic to entrepreneurial action. According to Kirzner (1997), entrepreneurship requires the discovery of new means-ends relationships rather than the optimization of existing ones. As they search for solutions to problems that are still imperfectly defined, as they explore applications of new technologies that are not fully developed, and as they take guesses about which opportunities are worth pursuing, entrepreneurs experience a high degree of uncertainty and ambiguity (Van de Ven and Polley, 1992; Garud and Van de Ven, 1992; Nicholls-Nixon, Cooper and Woo, 2000). According to Weick (1995), in fact, ambiguity arises in the presence of a poor understanding of the cause-effect relationships that underlie a phenomenon, when information is problematical and it therefore becomes difficult to assess the consequences of our decisions. In such cases, decisions call for an act of sense-making - i.e. the attribution of meaning to a complex reality, an act of interpretation that gradually imposes an order on reality and helps "make sense" of the external environment (Weick, 1995).

Learning in an entrepreneurial venture, then, seems to resemble more what in the management field has been termed higher-level, generative learning, as opposed to lower level, adaptive learning (Fiol and Lyles, 1985; Miner and Mezias, 1996), whereby adaptive learning involves the development of behavioral routines that allow an organization to perform a repetitive task in an increasingly efficient and effective way (e.g. Cyert and March, 1963; Nelson and Winter, 1982). Indeed, a balanced combination of generative and adaptive learning is required to support long-term growth, as the exploitation of commercially successful new ideas provides the resources to support new exploration (Mintzberg and Waters, 1982). However, the exploration of new combinations of resources is a qualifying feature of entrepreneurial action (Schumpeter, 1936; Kirzner, 1977). Learning in an entrepreneurial venture has a creative component that goes beyond repetition and incremental optimization; it occurs in ambiguous contexts, and often involves the development of completely new solutions or radically innovative products. As the task to solve does not involve repetition, the outcome of generative learning is not so much a change in routine behavior, as a change in the knowledge structures that sustain interpretation and action (Friedlander, 1983; Lyles and Schwenk, 1992).

Successful entrepreneurial innovation, therefore, requires an increasing understanding of contexts of use and functional implications of alternative solutions. At the start of an innovation process, ambiguity is usually high: product concepts are new and ill defined, experience of use is limited and the context of use is complex (Clark, 1985). Learning takes place as entrepreneurs gradually manage to make sense of the connections between the different technical subsystems, product functions, customers' preferences, market structure, etc., (Weick, 1995).

External contributions

A second distinctive feature of learning in an entrepreneurial venture seems to be its reliance on external contributions. Research shows how individual social capital positively affects the capacity of nascent entrepreneurs to successfully complete their projects (e.g. Davidsson and Honig, 2003). Although entrepreneurs play a pivotal role in the development process, in fact, they rarely possess all the competencies required for the success of the venture. Typically, entrepreneurs possess a good knowledge of the market and the customers, and often a certain degree of technical competence in his field. Often the actual realization of these ideas, however, requires not only financial resources, but also skills and competencies that must be obtained from industrial, commercial and research partners, consultants, designers, etc (Birley, 1985; Dubini and Aldrich, 1991; Larson, 1991). In entrepreneurial ventures, then, learning often arises from the interaction of a number of actors that are in part external to the organization. The support of scientists, engineers and other actors that possess knowledge and skills complementary to the entrepreneurs' is often required in order to move from the initial idea to the actual product or process.

As the complexity of the technological bases and the dispersion of the sources of expertise increase, in fact, innovation requires entrepreneurs to develop and manage a network of collaborations with partners of a different nature (Powell, Koput and Smith-Doerr, 1996). The range of actors involved in the learning process extends from the entrepreneur – locus of coordination and impulse for the projects – to his close collaborators inside the company (technicians, engineers, marketing people etc.) and a web of external partners, consultants and suppliers, who provide specific knowledge and competencies to the project. Industrial or research partners, suppliers, clients, consultants, venture capitalists offer a contribution that often goes beyond the physical content of the exchange: they contribute to the development and refinement of the technologies embodied in new products and services and of the organization that produces and delivers them.

Limited resources

Finally entrepreneurs tend to face an intrinsic scarcity of resources. Several studies suggest that entrepreneurs operate under conditions of serious resource constraint and are constantly struggling to obtain from the environment the complementary assets and resources (capital, first, but also technology, skills, support, etc.) required to develop and commercialize their ideas (Kirchoff, 1994; Garnsey, 1998). Resource constraint in an entrepreneurial setting, however, is not just a matter of money. Entrepreneurial activity requires frequent decisions about what opportunities are worth pursuing, and, among the various solutions available, which are worth exploring. In other words, entrepreneurs are often called upon to decide what issues are worth their attention, and how much of their personal time should be allocated to current product improvement and new product development (Gifford, 1988). Considering that entrepreneurs tend to be the prime movers of all the projects they start, as they constantly provide direction, coordination, and enthusiasm to the other persons involved, their time and attention are often as critical and as scarce as money.

This limited pool of available resources periodically imposes choices regarding which paths to follow, which ideas to develop, which expectations to attend to, and, most of all, whether it is worth persisting with certain projects or not. These decisions are complicated by the uncertainty that surrounds the commercial return of most initiatives. As Van de Ven and Polley write, "a central problem in managing and investing in innovations is determining whether and how to continue a developmental effort in the absence of concrete performance information (1992, p. 92)."

In summary, distinctive characteristics of entrepreneurial ventures may influence the learning process in the following ways. First, entrepreneurial innovation is concerned more with exploration of new combination of resources rather than with optimization of existing ones. Learning, therefore, requires the gradual reduction of ambiguity surrounding the connection between resources, technologies and customers' needs. Second, learning in entrepreneurial innovation is only partly under the entrepreneurs' control. Some of the activities that contribute to the overall learning process are actually performed by consultants, technicians, scientists, specialized suppliers, etc., whose contributions have to be coordinated and integrated by the entrepreneurs. Finally, the scarcity of resources that affects most entrepreneurial ventures may affect learning in entrepreneurial innovation, as limited capital, time and attention may impose periodic decisions about what paths are worth exploring, for how long and with what degree of commitment. Shortage of time, money and attention may also aggravate the difficulty of facing ambiguous situations (McCaskey, 1982). We believe that increasing our understanding of the learning processes that underlie entrepreneurial innovation requires us to address the implications of these specific conditions affecting entrepreneurial ventures. In other words, explanatory frameworks should not only address how entrepreneurs gradually reduce the ambiguity surrounding their projects, but also consider how external contributions and the scarcity of resources may affect the process.

4. Research Method

Introducing a recent special issue of the *Journal of Business Venturing*, Gartner and Birley (2002) observe how qualitative research is rarely used in the entrepreneurship field. The use of a qualitative approach, however, is appropriate to the study of phenomena, such as learning, which require a methodology that can trace processes as they unfold over time, and is sensitive to the broader context and the perspective of the involved actors (Miles and Huberman, 1994; Miner and Mezias, 1996; Lee, 1999). Past research, for instance, have fruitfully adopted qualitative methods for data collection and analysis to investigate the learning processes that take place as alliances evolve over time (Ariño and Garcia De La Torre, 1998) or as organizations adopt unfamiliar technologies (Woyceshin, 2000). Following this approach, in this paper we adopt a method based on comparative case study (Eisenhardt, 1989, Langley, 1999), in order to explore process-related conditions that influence successful learning in entrepreneurial innovation.

Research setting

In order to minimize the impact of environmental and context-specific conditions, we analyzed two development processes that were conducted within the same organization, roughly at the same time, and under the direction of the same person. The research setting is Futureplast, a small company whose core activities lie in the research and development of new technologies for the lighting industry. Futureplast s.r.l. was founded in 1989 by two partners, Mr. Guzzoletti and Mrs. Nobili, to produce low-cost, decorative iron down-lights for low-tension white-heat lamps and halogen lamps. Mrs. Nobili, took charge of marketing and sales activities, while Mr. Guzzoletti oversaw product development and operations. Four years later, the rising pressure of Chinese competitors induced the two partners to turn to product differentiation. In the following years, new professional and outdoor lines were added, and iron lamps were replaced by aluminum items less affected by Oriental competitors. Furthermore, decorative lines were substantially restyled in order to re-position products in more profitable segments. At the time of our study, Futureplast focused on the highest value-added phases of the value chain (design, engineering and installation), investing more than 5% of its annual sales in research and development, and completely outsourcing the actual production and assembly of components – based on mature and widely available technologies – to more than eighty small local companies, employing around 130 people. Its catalogue comprised around 300 products, about a hundred of which had been introduced in the three previous years. The company's products were sold in over 50 countries, its revenues topped 12 billion liras (around 6 million euros) and it employed nine persons, most of which directly involved in research and development.

According to criteria widely used in the literature, Futureplast can be defined an entrepreneurial firm. Mr. Guzzoletti and his staff are constantly engaged in development processes that lead to the design of new products or production processes, and sustain firm growth (Schumpeter, 1934; Carland, Hoy, Boulton and Carland, 1984). Prior to our study, between 1994 and 1996, the company introduced around a hundred technological and stylistic product innovations and four substantial innovations in production technologies. In the years that followed, the company kept expanding its product range by adding new lines, like underwater items and in-ground installations, and acquiring or developing new technologies for manufacturing aluminum and stainless steel products. Its revenues have increased steadily since the foundation, and in recent years the company has moved three times in order to accommodate new labs and warehouses. Furthermore, Mr. Guzzoletti conforms to the seminal definition by Stevenson and Gumpert (1985), according to whom entrepreneurship can be conceived as pursue of opportunities for innovation – three of which will be described in this paper – regardless of the resources currently controlled. In fact, Futureplast's expansion and growth relied extensively on external contributions, also thanks to the geographical location of the company – near Milan, in the middle of the industrial district of Brianza Milanese. Manufacturing and assembling was outsourced to specialized producers of lighting components, located in the surrounding industrial district. Product design and styling was commissioned to professional industrial designers, widely available in the Milan area. Development of new products and technologies often involved external partners like engineering consultants or research labs, located in the district.

Our study focused on two major development projects aimed at exploring new business opportunities. One project aimed at reproducing a plastic cable, which had the potential to become the dominant technology in the lighting industry. After several months of unfruitful efforts it was abandoned. The second project, conversely, led to the successful development of a laser technology for high-quality manufacturing of glass furniture complements. The fact that both projects aimed at reproducing already existing technologies allowed us to rule out the possibility that in one case the goal of the project was simply impossible to achieve. While these technologies were already available, they were not known to the company and their commercial applications were initially not clear. In both cases, therefore, the development efforts involved exploration, experimentation and risk-taking on the company's side. Figure 1 summarizes the chronology of the processes and the study.

Figure 1 about here

Data collection

Data collection was mainly based on semi-structured interviews with the relevant actors involved in the process: the two partners, Mr. Guzzoletti and Mrs. Nobili, an employee from Futureplast who took part in both projects, and two representatives of major external partners for each project, CNR and CISE-ENEL. In the first round, we interviewed all the internal actors, in order to collect background information on the company (history, strategy, structure, etc.) and preliminary information on the two projects. Interviews took place in early 1997, as both projects were in an early stage. A second round of interviews was conducted some time after the termination of the first project, while the second project was in an advanced stage (see figure 1). In the second round we interviewed Mr. Guzzoletti and his staff again, and we interviewed two external actors for the first time. Other informal interviews with Mr. Guzzoletti followed, which helped us to clarify minor points and check the validity of our tentative interpretations. As some informants were interviewed more than once, in total we conducted nine interviews with five different informants. Interviews were aimed at identifying the main phases of the process, from the initial stimulus to the result, and followed a common structure. Our informants were first asked to reconstruct the story of the project as they lived it – or they were living it, trying to distinguish facts (how it started, who was involved, etc.) from personal observations. We then asked them to describe in more detail their contribution to the projects, the nature of their involvement (contractual terms, expected benefits, etc.) and the interaction with other actors. During the interviews, we stimulated our informants to specifically refer to facts and events that left a trace in their memory; however, we never referred explicitly to concepts like “knowledge” or “learning”, so that our own guiding framework did not condition their description. Each interview lasted between one and two hours and, in most cases, they were tape recorded and transcribed. Both researchers were present at most interviews. Field notes and transcriptions were examined after each interview in order to discuss emerging themes and prepare the following interviews. Some interviews were followed up either personally or by telephone, in order to collect additional information and refine the emerging framework. Multiple, open-end interviews helped us to collect both factual data and personal impressions and to reconstruct a detailed chronology of the process. Although our reconstruction was based on our informants’ recall, combining multiple perspectives helped us to move beyond individual perceptual biases and alleviated potential recall problems.

Data analysis

Gartner and Birley (2002) have recently lamented that qualitative research in the entrepreneurship field often fails to go beyond simple description to propose an explanation of the observed phenomena. Developing an explanatory framework, however, was central to our research. In order to move beyond simple description we combined what Mohr (1982) calls “variable” analysis and “process” analysis. We first searched our data for similarities and differences that let us identify a number of key concepts. We then looked for longitudinal connections between these concepts that suggested relations of causality – what Miles and Huberman (1984) call “stories”. According to Miles and Huberman (1984) moving back and forth between concepts and stories is essential to the development of a good explanatory framework.

Data analysis used common methods for grounded theory building (Glaser and Strauss, 1967; Miles and Huberman, 1984) and followed the logic of comparative case study, according to which empirically grounded theoretical propositions are derived from the search of discriminating variables that appear to influence the outcome of an observed process (Eisenhardt, 1989). In our case the discriminating variable was success or failure in developing the target technology. The analysis of data combined within-case analysis with cross-case comparison, and can be summarized as a three-step process.

The first part of the analysis was based on an accurate coding of the interviews. We searched interviews for passages that contained references to the development process. The search was conducted independently by the researchers; later comparison of independent analysis showed a substantial agreement. Minor differences were solved through mutual consensus. At this stage, our goal was to identify key variables that could be associated with the way the projects advanced, were re-directed or eventually terminated. The literature on organizational learning and innovation management offered us a terminology and conceptual references that helped us to develop labels for the identified emerging variables. For instance, the passage “Monteverdi’s help was fundamental in the selection of the most appropriate research center for a chemical analysis (…)” was first coded as “boundary-spanning role”.

The second step was aimed at the identification of variables that could account for the different outcome of the two projects. Discriminating variables emerged from the systematic search of analogies and differences in the two processes, separately conducted by the two researchers. This procedure helped us reduce the potential influence of post-rationalization as we tried to move beyond our informants’ explicit attributions of causality, in order to identify the underlying variables that discriminated between the two processes. In some cases, the comparison led to a homogenization of concepts into broader categories: “preliminary search” and “past experience”, for instance, were grouped into “prior related knowledge”. Other variables were dropped because they assumed the same state (high or low, absent or present, etc.) in both projects (in both cases, for instance, Mr. Guzzoletti relied on the initial help of Mr. Monteverdi) and no causal relationship with the different outcomes could be plausibly inferred. In the end, we isolated four variables, which assumed a different state in the two processes and whose combined effect seemed to explain the observed differences: the degree of perceived causal indeterminacy, the amount of prior related knowledge, the degree of control over the process, the uncertainty associated with the commercial return. Findings from this stage are reported in the next section, after a brief description of the cases.

In the final part, a longitudinal analysis of the cases allowed us to capture the evolution of the interaction between the critical variables emerging from the cross-case analysis. We searched for causal associations between the four variables, following Miles and Huberman’s (1984) methodological recommendations to develop a causal network – i.e. a display of the most important variables and of the relationships among them. We relied on chronological tables to order variables and critical events in a longitudinal order. A number of iterations between theory and data eventually led us to weave these variables into a meaningful pattern: an emerging conceptual framework centered on the entrepreneur, relating success and failure to self-reinforcing interaction among these variables producing positive or negative effects on the learning process. Feedback from Mr. Guzzoletti helped us refine our tentative explanation. The resulting model is displayed in figure 2.

5. A tale of two projects

The analyzed projects were carried out, almost simultaneously, over a time period that goes from spring 1996 to winter 1998. As anticipated, both involved the reproduction of already existing technologies, samples of which came into Mr. Guzzoletti's possession during visits to industrial fairs. In the spring of 1996, at an industrial fair in Munich, a plastic cable that could be used for the conduction of light caught Guzzoletti's attention. Because of its physical properties the cable could have revolutionized the dominant technology for light conduction, if a system to reduce production costs had been devised. Back home, Guzzoletti started a project to investigate the possibility of reproducing the cable technology. The first step was hiring Mr. Monteverdi, a young physicist from the University of Milan, Politecnico. In Guzzoletti's words:

> The employment of a person with a solid scientific background was meant to provide structure and method to the research activity carried out at Futureplast, and to open up new channels towards the external acquisition of new, front-line scientific knowledge.

Monteverdi was assigned the task of assisting in the collection and interpretation of scientific information regarding light-conduction technology. Over a two-month span, he undertook an accurate study of the existing literature on the most developed methods for the conduction of light. At the same time, Mr. Guzzoletti contacted the company that had produced the cable. They agreed to send a couple of samples of the material; however, they were not willing to transfer any kind of information, not even on the basis of a formal cooperation. Most of the information collected by Mr. Guzzoletti and his staff came from a review of the scientific literature on optical fibers and from a search of the American patents on inventions. These sources, however, were not so rich as expected, so Mr. Guzzoletti was forced to look for an expert partner who possessed the required knowledge and instruments to carry out an exploratory study on the new material on behalf of the firm.

He decided to turn to the academic world. At first, universities were reluctant to cooperate with an entrepreneur who did not possess an academic degree. In this respect, the presence of Mr. Monteverdi helped select and contact academic institutes, and establish the relationship with the one that was finally chosen: a research facility belonging to the Consiglio Nazionale per la Ricerca (CNR), a public academic institution that possessed qualified personnel and advanced scientific equipment. The contract implied a fixed reward for the analysis of the chemical and physical characteristics of the cable, and for the search of its basic components. Research started soon afterwards and took place in the laboratories of CNR. The study was carried out essentially by CNR personnel. Mr. Guzzoletti and Mr. Monteverdi were present at the first few tests, but, as both admitted later, they did not possess the required knowledge to understand what was going on, and soon they just waited for the periodic communication of results. Meanwhile, Futureplast staff was waiting for positive signals to start studying a process that allowed the production of the new material at a reasonable cost; designing a production process, in fact, required the product to be defined beforehand. Within six months, 20 out of the 21 chemical components required by the new material were identified and part of its revolutionary properties was discovered. Without the missing component, however, Futureplast was unable to adequately master all the technological aspects necessary for the production of the new cable. At the end of the semester, then, Mr. Guzzoletti decided to abandon the project and to write off the investment as unsuccessful.

At about the same time, Futureplast staff was involved in another major development project, which was not strictly related to the lighting business. In September 1996, during an international exhibition in Moscow, some crystal objects caught Mr. Guzzoletti's attention because of the extreme quality of the engraving of their internal surfaces. Seeing a potentially rewarding opportunity for diversification, Mr. Guzzoletti decided to investigate the technological process that had produced those objects. Although no information was available at the exhibition, his guess was that they could only be produced with laser technology. Guzzoletti was already familiar with laser technology. Not long before, they had explored laser technology in the preliminary phase of a project aimed at developing an application for entertainment – so called “laser shows” – soon abandoned when it had become clear that it required a much larger investment that Futureplast could afford. The search had nevertheless led to amass a considerable body of literature in a specialized library and to acquire elementary notions of physics required to understand laser technology.

Soon after having returned from Moscow, a casual chat with Mr. Nava, an engineer at CISE-ENEL, confirmed Mr. Guzzoletti’s guess about the origin of the crystal object. CISE-ENEL is an advanced research laboratory owned by a large electricity supplier, which at that time possessed the highest level of expertise in laser technologies in Italy. Mr. Nava was one of CISE’s experts in laser technology. He had already met Mr. Guzzoletti when the latter was investigating the laser-show technology. Months later, Mr. Nava was visiting Futureplast again looking for external orders on research activities. Mr. Guzzoletti showed him the glass objects and advanced the idea that they were the product of a sophisticated laser system. It turned out that Mr. Nava had been at the same exhibition and had noticed the same objects. In the past, he had collaborated with some Russian universities and he had already made some preliminary study.

CISE was not a direct competitor and there was no risk that they could make commercial use of the knowledge developed in the project, so Mr. Guzzoletti decided to collaborate for the development of an advanced system for manufacturing glass products with laser technology. The agreement (annual collaboration contract, commissioned by Futureplast) was expressed in general terms: CISE would be rewarded by man-hours for their collaboration on the research. The fundamental goal was to define the best possible use of laser technology with regard to the characteristics of the manufacturing technology.

Much research and development activity took place in a laboratory set up by Futureplast for the purpose. The only phase that was carried out at CISE’s labs was the simulation of the production process. The initial phase of the project was dedicated to the identification of the most appropriate laser source and to the design of the architecture of the system. The fundamental problems to be solved were related to the high costs and to the dangers involved in the use of a laser source. The search for a solution involved several computer simulations that allowed the researchers to reproduce the behavior of the system and to analyze its critical elements. The development and engineering of the system took place at Futureplast, and involved extensive experimentation and reverse engineering in order to gain an intimate knowledge of the technology of laser sources and of their electronic support. In order to achieve the full automation of the system and a smooth and effective integration of all the technological subsystems, the development and production of the first prototype was carried out by a team composed by Mr. Nava and Mr. Guzzoletti, two technicians from CISE and one from the laser supplier, plus other external consultants, involved in the solution of specific problems of technological subsystems (mechanics, electronics, etc.). In the second half of 1998, a functioning prototype was successfully produced, amid the enthusiasm of all the team members.

6. Conditions of success and failure in the observed projects

Comparing the two cases, four variables emerged as discriminating between the successful and the unsuccessful story (see table 1): the degree of perceived causal indeterminacy, the possession of related knowledge base, the degree of control of the process, the perceived uncertainty of returns.

Table 1 about here

Perceived causal indeterminacy

A first difference between the two projects was related to the characteristics of the fundamental problem to be solved. In the first case, the attention of Mr. Nava, the main research partner, had already been attracted by laser systems even before getting in touch with Futureplast. As Mr. Nava admitted:

> (…) the basic ideas for the project had already taken shape, because I had been working in the laser field for years and our ideas had already been clarified by our preliminary contact with Russian technicians. In other words, we had problems to solve, but we had already taken some steps in earlier experiences, even though we had some substantial changes to make in order to improve productivity and precision.

Mr. Nava and Mr. Guzzoletti used words like "rather structured" and "well outlined" to describe the problems posed by the design of a new laser system. A preliminary review of the available optical sources had clearly indicated the critical issues to be solved: ensuring safety for the operators and raising precision and speed above what Mr. Guzzoletti and Mr. Nava thought was the industry standard. Although at that stage Mr. Guzzoletti and Mr. Nava did not know yet how to solve these problems, they had at least a clear perception of the main issues to be dealt with, and the types of expertise to involve:

> [after the preliminary stage] we sat down and reviewed all the different components we needed and where we could source them. In some cases, we already knew whom we could turn to. In others, like the optical source, we started searching for suitable suppliers (…)

A computer simulation helped define specifications compatible with the desired productivity levels, which guided the subsequent stages of the process, as Mr. Guzzoletti, Mr. Nava and their staff explored different solutions.

Compared to the laser system, the reproduction of the plastic cable involved basic research, whose steps were perceived by Mr. Guzzoletti as far less "clear" than those required by the integration, albeit in an innovative and unconventional way, of existing technologies (laser technology, crystal manufacturing, electronics, and information technology). The initial search through existing patents did not make the task ahead any clearer. As Mr. Guzzoletti observed, the review of the existing literature let them "exclude some research paths, but did not really show [them] a way to go." He knew that the first task ahead was the identification of the chemical structure of the cable. Yet, although he had a clear perception of his ultimate goals – i.e. identifying the basic components of the polymer and finding a relatively inexpensive production process – the nature of the experiments involved in the early stages and ran by CNR technicians were rather obscure to him:

> In the beginning I asked them to explain me what they were going to do, and of course they did it (…) I understood that discovering the components required running several trials, but I could not grasp more than that.

In the case of the laser system, instead, the causal connections between the end – the development of the system – and the means to get there – e.g. the hierarchy of different design issues (productivity, precision, speed, safety, etc.) – were perceived more clearly. An initial difference between the two projects, then, seems to be related to the diverse understanding of the causal relationships connecting means to ends, or, in other words, to different degrees of causal indeterminacy in the tasks that Mr. Guzzoletti was facing.

The concept of causal indeterminacy refers to the degree of understanding of the causal relationships that underlie a phenomenon (Orton and Weick, 1988). Orton and Weick (1988) observe that a certain degree of causal indeterminacy is intrinsic to any non-routine task or problem – and therefore also to entrepreneurial projects. Usually, individuals reduce the degree of causal indeterminacy in a task as they start acting and trigger reactions from the environment that, once interpreted, increase the sophistication of their representation of the environment (Weick, 1979). To some extent, then, causal indeterminacy can be reduced through exploration and experimentation that help individuals to improve their understanding of their task. Indeed, one of the problems might have been perceived as more structured also because the solving process was already at an advanced stage, and some preliminary analysis conducted by external parties had helped clarify most issues.

Prior related knowledge

Causal indeterminacy, however, is not entirely intrinsic to a phenomenon or a technology. The perception of a causal relationship as ambiguous depends also on the richness and accuracy of the mental frameworks that we use to interpret the observed phenomenon (Glassman, 1973; Orton and Weick, 1988). In this respect, as we increase our knowledge and understanding of a certain phenomenon - i.e. we increase the richness and the accuracy of our mental maps - we reduce the causal indeterminacy that we perceive (Weick, 1995). Indeed, the comparative analysis of the two cases pointed at the role of the amount and type of knowledge possessed by the entrepreneur in his capacity to make sense of the problems he was facing.

In the case of the plastic cable, although the potential application of the cable technology had a closer link to the core business of the company, the development of the new technology required fundamentals of optics and chemistry that were far from anything that he and his staff mastered. Mr. Guzzoletti explicitly related his initial difficulties to his lack of competence in the core technologies involved ("You see, I have a technical degree and some practical experience in engineering, but I am not a chemist") and observed how Mr. Monteverdi, who was a physicist, could not be has helpful as in the other case. Mr. Monteverdi added that the search of American patents did not help them improve their knowledge of the phenomenon much.

In the second case, instead, Mr. Nava had been working in the field for twenty years, and at the start of the project Mr. Guzzoletti was already familiar with laser technology. A few months earlier, exploring the possibility to start a production of "laser shows", he had collected and reviewed the existing scientific literature on physics and laser technology, in order to learn the scientific fundamentals of laser technology. With the help of Mr. Monteverdi, a comprehensive library had been set up in Futureplast laboratories, by thoroughly searching local research centers, and by integrating the search with the acquisition of texts at that time published only in the United States. A systematic review of American invention patents had helped them understand the fundamental characteristics and the recent evolution of laser technology. "More than 50 kilos of catalogues on laser systems, sources and components" – as Mr. Monteverdi referred to them – were collected. As Mr. Guzzoletti remarked, the review of American patents helped them grasp the basic knowledge required to effectively reverse-engineer all the components they were using. Indeed, Mr. Nava explicitly indicated Mr. Guzzoletti's technical skills and understanding as one of the main factors affecting the smoothness of the process.

Past studies (Cohen and Levinthal, 1991, Szulanski, 1996) have shown that the capacity of an organization or a business unit to acquire knowledge from another organization or unit is affected by the amount of related knowledge possessed. Cohen and Levinthal (1991) described this capability as “absorptive capacity”. Prior related knowledge, in this respect, is expected to increase the capacity to appreciate the value of external knowledge and to facilitate its understanding and adoption. Evidence from the comparative analysis of the cases suggests a similar phenomenon, whereby the possession of the required knowledge base helps reduce, in the initial stage, the perceived indeterminacy in the task ahead. In this respect, the role of Mr. Monteverdi was fundamental, not only as a “broker” of books and scientific contacts, but also because he had introduced Mr. Guzzoletti to the basic terminology and concepts of physical laws, providing him with sufficient knowledge to understand the nature and implications of the basic technologies of the systems.

Control over the process

Another fundamental difference between the ways the two projects were managed seems to be related to the degree of control that the focal actor and decision-maker, Mr. Guzzoletti, was able to exercise over the process. We define control in cognitive terms, as the capacity of the entrepreneur to monitor a process and to affect its direction. With the exception of a number of computer simulations, which helped produce specifications for the system in an early stage, most research activities that led to the successful development of the laser system took place at Futureplast labs, where Mr. Guzzoletti was working in close contact with the external technicians. In this way, he was able to observe and discuss their tests and trials. Reverse engineering was systematically done on all the components of the system in order to acquire all the relevant knowledge, especially on the electronic components and on the laser source, so that the company could, later, reconstruct the whole system autonomously. As Mr. Guzzoletti recalled:

> Every day, at the end of the working day, when the external technicians had left, we locked ourselves up in the lab until 2.00 o’clock in the morning to repeat every test and to disassemble every component, until we were sure that we had understood their nature and their potential. In this way, we gained an intimate knowledge of every component, which made it easier for us to develop and improve the integrating system.

At the end of the project, the profound knowledge of the technological subsystems acquired by Mr. Guzzoletti, Mr. Nava and their staff allowed them to reproduce internally all the components – with the exception of the optic source – and to adapt them to the specific needs of the system. As Mr. Guzzoletti observed:

> [the internally designed components] were not only cheaper, but even better that those we found on the market. More fit to the system. Initially we had turned to commercial components in order to save money. In fact, our second prototype used almost only re-designed components.

In the case of the plastic cable, on the other hand, technology development was largely outside Mr. Guzzoletti’s control. Experiments took place at CNR, where Mr. Guzzoletti was “delegating and observing”, as he himself remarked. Research activities, then, were carried out mainly by CNR’s researchers, while Futureplast was involved only as an external observer. Mr. Guzzoletti and his staff, unable to participate in the analyses that were carried out by CNR, gradually detached from the process and passed by the labs only to get the results of the tests. As Mr. Monteverdi recalled:

> We didn't feel competent enough and, as a matter of fact, we acknowledged the leadership of CNR's researchers over the project. "They are the ones who know" - we thought, so we essentially gave up the direction of the phases of the process. Unfortunately, CNR's researchers were not so interested in the actual outcome of the project.

Although there is no evidence that a higher degree of control would have led to the discovery of the missing element, what ultimately undermined the possibility that further research efforts would eventually produce a result was the gradual loss of confidence in the potential return of the project, which, as we will discuss in the next paragraph, was brought about by the absence of control over the process.

Perceived uncertainty of return

Cognitive risk theory posits that individuals select investments according to their assessment of the probabilities of risk and reward associated with the available alternatives, in an effort to maximize their utility (Kahneman and Lovallo, 1993). In the case of Futureplast, another fundamental difference between the two projects was the actual capacity of the entrepreneur, Mr. Guzzoletti, to assess the extent of the potential return coming from each project, and the associated risk.

Mr. Guzzoletti's assessment was critical because, although other parties were involved in both projects, their successful completion depended chiefly on Futureplast's commitment. Let us consider the failed project first. CNR is an academic organization with no commercial drive. Furthermore, even from an academic point of view, CNR had no specific interest in fiber optics, and Mr. Guzzoletti and Mr. Monteverdi expressed the opinion that CNR did not seem much interested in investing on the development of specific competence in the field. For CNR, the project was just another external research order that they fulfilled diligently, but with no particular commitment. As a researcher we interview observed, "[CNR] often work[s] for companies. They take us samples and ask us to analyze their chemical structure." Furthermore, the contract did not relate the compensation to the achievement of a specific result, but only to the carrying out of a series of tests. In other words, Futureplast was the only party really interested in the eventual completion of the project. The decision whether the project should be terminated or not, therefore, rested only in the hands of Mr. Guzzoletti, who at that stage, as we have mentioned, had little understanding of or control over the process, as he himself observed:

> The successful development of the plastic cable was, unfortunately, largely outside our control and CNR did not seem to be so keen in investing in optic-fiber technology. On top of that, even though we had successfully identified the 21 components, we would still have had to find a way to produce the cable at a reasonable cost, before we could finally start to study its application in the lighting industry. Futureplast is a small company and we can't afford to wait that long for such an uncertain return on our investment.

Behind Guzzoletti's decision to terminate the plastic-cable project and to dedicate most of its time and attention to the development of the laser system, there seems to have been a gradual loss of confidence in the success of the process. Futureplast had been expecting results from CNR for months in order to start the feasibility study of the production process. At the expiration of the contract, however, time and money invested until then had produced results inferior to expectations: a component was still missing and there were no certainties about the time required to identify it. The commercial return on the investment was becoming more and more distant in time and difficult to assess. On the other front, the potential return associated to the successful development of the laser system was becoming clearer and clearer, as the initial steps in the collaboration with CISE-ENEL were producing encouraging results in terms of the structuring of the problem. Later, the systematic respect of budgets, timetables, and expected milestones, gradually reinforced Guzzoletti's confidence in the success of the process and the motivation associated with the incentives associated to it, as implied in his narrative:

> With time, I got more and more enthusiastic about the laser. I could tell that we were slowly getting somewhere. (…) After the first prototype was built, I knew that it was just a matter of little improvements before we could finally start thinking about the market.

While the identification of the components of the plastic cable was only the first step in a process where other substantial issues, such as efficient production of the cable, were still unsolved, the development of the laser system seemed to have an immediate market application.

7. Self-reinforcing cognitive processes in entrepreneurial innovation

The longitudinal analysis of the cases suggests that the four variables mentioned in the last section did not affect the learning process separately. Their combined action underpinned a self-reinforcing virtuous (or vicious) circle that affected the effectiveness of the learning process by influencing the allocation of limited attention and resources to the projects.

Past studies of risk taking and decision-making have highlighted the risks of vicious circles trapping managers and entrepreneurs in dangerous downward spirals, as disappointing results lead to further risk taking, increasing the likelihood of further disappointment. Staw and colleagues (Staw, 1976; Staw and Ross, 1978; Staw and Fox, 1977) introduced the concept of escalating commitment to describe the observed tendency to increasingly commit resources to an unsuccessful course of action, with the frequent consequence of furthering losses. Later, Bateman and Zeithaml (1989) observed how the perceived scarcity of organizational slacks might lead to more risky behavior, and therefore expose decision makers to potentially more severe repercussions of negative results. More recently, Simon, Houghton and Savelli (2003) found that small business owners who are unsatisfied with current performance tend to introduce more risky products, by entering unfamiliar markets or investing a high amount of resources. Such behavior was eventually associated with lower subsequent product performance.

Our findings showed a somewhat different picture. In the case of Futureplast, shortage of resources seemed to restrain commitment to a seeming unsuccessful course of action, rather than stimulate it. In fact, a comparison of the two projects showed the increasing commitment of Mr. Guzzoletti to the laser-system project – reflected in the renewal of the cooperation contract with CISE-ENEL – and a decreasing involvement in the plastic-cable project, culminating in the decision not to proceed in the search for the missing component. This explanation reflects an interpretation shared by the two main actors involved in the projects. Both Mr. Guzzoletti and Mr. Monteverdi, in fact, expressed their confidence that "given time and resources" they could have made it even in the second case. Of course this may or may not be actually true, but Mr. Guzzoletti's point of view on the matter did not relate failure to an intrinsic difficulty of the problem to be solved, but to the lack of resources that affected the company:

> My time is limited and Futureplast resources are what they are. There are only so many projects that we can run at a certain time and sometimes we have to make a choice.

While allocation of substantial resources is not always sufficient to guarantee successful results, in the absence of resources and commitment the likelihood of success may decrease dramatically.

As we have observed in the last section, the decreasing commitment to the first project seems to have been led by the increasing uncertainty associated with the commercial return of the plastic-cable project, compared with the growing confidence on the successful development of a marketable laser system. This difference was partly related to the different degree of control over the process exercised in the two cases. In the case of the plastic cable, as research was carried out essentially in the CNR's lab, there was no way for Guzzoletti, as we have mentioned, to assess the likelihood of success and failure and the time frame required for the completion of the research. In the other case, setting up an in-house laboratory helped Guzzoletti keep a close control on the advancement of the project and make more precise estimates of costs, time and potential returns.

It is possible also that Guzzoletti's decisions were affected by the "bold forecast" bias described by Kahneman and Lovallo (1993), that is the tendency of members of a project team to produce over-optimistic forecasts about the relative risk and the expected completion time of the project. It is possible, therefore, that the gradual loss of faith in the first project did not reflect a lack of information, but a gradual shift from an over-optimistic "insider view" to a more pessimistic "outsider view" that followed the diminishing involvement in the process (Kahneman and Lovallo, 1993). Regardless of the underlying cognitive mechanism, evidence from our study suggests a relationship between control over the process and the perceived uncertainty of results. Whether this connection depends on a rational analysis of the situation or on the heuristic bias described by Kahneman and Lovallo, however, cannot be inferred from our data.

What seems to have affected the different capacity of Futureplast staff to control the processes is the amount of prior related knowledge. In the first case, in fact, the scarce degree of control over the process did not depend only from its physical localization, but also, as reported by Mr. Guzzoletti and Mr. Monteverdi, from their lack of background knowledge in chemistry and optics, which made it practically impossible to follow the trials. Indeed, as we have seen, the entrepreneur's lack of competence in chemistry was the main reason why they had to turn to an external partner to run all the trials involved in the early stage of the project. In the second case, instead, Guzzoletti possessed the knowledge base required for the design of the new technology and could follow the development project step-by-step, actively taking part in it and coordinating the efforts of the other partners.

Taking an active part in the project seems to have ultimately affected the entrepreneur's commitment and the way he distributed his resources among the project: not only finance, but also time and attention. In fact, while in the first case Guzzoletti soon stopped participating, even as an observer, to the tests that were run at CNR, in the second he was getting more and more involved in the development of the system. The increasing allocation of time and attention produced as a side effect a substantial increase in the related knowledge base: involvement in the research activity led to a significant enrichment in Guzzoletti's expertise in the design of laser technology, as demonstrated, in the final stage of the process, by the capacity to reproduce and improve the design of all components but one - i.e. the laser source, whose core technology was, incidentally, based on optics. Also, increased involvement in the project, associated with enriched knowledge, reduced the intrinsic causal indeterminacy perceived in the task to complete, with a positive effect, again, on the degree of control.

Figure 2 about here

In sum, the comparison of Futureplast's different stories of success and failure in technology development suggests the existence of a self-reinforcing cycle driving entrepreneurial learning (see figure 2). This virtuous circle is sustained by the growing allocation of resources, time and attention to projects perceived as more promising by the entrepreneurs, and results in the continuous upgrade of the entrepreneur's knowledge base and in the gradual reduction of the causal indeterminacy associated to the task to perform. As some opportunities come to be judged as "more promising" than others, they may receive an increasing amount of resources beneficial to further refine exploration and learning. Together with these variables, increasing control over the process and increasing capacity to estimate the extent and the likelihood of commercial returns are the cornerstone on which the process is based.

Besides highlighting the role of resource scarcity, our emerging interpretive framework provides also partial account of how other specific conditions affecting entrepreneurial learning influence the process. Earlier, we observed how exploration – conceived as the purposeful attempt to reduce the degree of ambiguity surrounding a task – is central to entrepreneurial innovation. Exploration is also central to our model, in which learning (or the failure of) is represented as the outcome of virtuous (or vicious) circles resulting in the gradual reduction (or persistence) of causal indeterminacy about the problems to be solved when moving from an initial intuition to a fully developed technology underlying a new product or process. Such representation of the process is consistent with Kirzner's observation that entrepreneurship is about the development of new means-ends relationships (in other words, other relationships of causality), rather than at the refinement of existing ones.

Finally, our model accounts also for the potential loss of control implied by the need to rely on outside assistance for critical learning activities. In both cases, the help of scientists and engineers from research centres was needed as Mr. Guzzoletti lacked the competence and the instrumentation required for running parts of the development activity. Yet in one case – the laser system – previously accumulated knowledge let Mr. Guzzoletti be an active part of the team since the early stages. In the other, lack of competence in optics and chemistry excluded him and his staff from any real involvement in preliminary research and eventually undermined his confidence in the potential return of the projects. Possession of related knowledge, therefore, may reduce the negative impact on resource commitment (hence on the learning process) of ending up promoting a project without feeling able to effectively assess the profile of risk and return.

8. Conclusions

In this paper we have reported findings from a comparative study of factors that promote or hinder learning processes in entrepreneurial ventures. We have argued that entrepreneurial innovation rests on a generative learning process aimed at the development of new knowledge structures embodied in an innovative product, process or service. We have observed how this type of learning is often the result of a collective process, which is only partly under the entrepreneurs' control. We have pointed out the severe limitation in time, attention and other resources that often affect entrepreneurial learning, imposing periodic choices about the continuation or the termination of developmental efforts.

In order to explore factors affecting learning in entrepreneurial innovation, we have analyzed two technology development processes within the same company. The comparison of a successful project and an unsuccessful one allowed us to investigate the underlying cognitive processes on the basis of rich, qualitative data. Our study, on the other hand, suffers from some limitations associated to its qualitative nature. While our focused longitudinal approach produced insight into the causal texture of the learning process, the boundaries of its validity are, by its own nature, limited. Our research setting was a specific type of venture: a small, autonomous, but established entrepreneurial firm. While the distinctive features of the learning context that we have identified seem to apply to other types of venture like start-ups or internal corporate ventures, we cannot exclude that other traits, specific to these forms, may affect the learning process in a different way. Furthermore, what we have studied is not the only type of learning that takes place in entrepreneurial ventures. Minniti and Bygrave (2001), for instance, investigate how entrepreneurs learn "how to be entrepreneurial". Other important learning processes occur as entrepreneurs start exploiting their innovations and managing growth. This, however, was not the focus of our study.

We believe, however, that the relevance of the study should not be judged from the generalizability of our findings, but on the insights that it generates in a relatively underexplored field such as entrepreneurial learning. The emerging framework extends previous literature on knowledge creation and technology development in entrepreneurial ventures, as it attempts to unpack the underlying process of generative learning. Evidence from the analysis suggests, in fact, that success and failure of development processes in Futureplast rested on a virtuous (or vicious) circle that brought Mr. Guzzoletti to dedicate more and more time, attention and resources to one project at the expense of the other. The self-reinforcement of the reduction in perceived causal indeterminacy, the upgrading in the personal knowledge base, and the increasing control of the process increased the entrepreneur's capacity to assess the commercial return of the time and resources dedicated to the project. The increasing clarity of the potential "return on the learning investment" and the systematic respect of budgets, timetables, and milestones reinforced Guzzoletti's commitment and confidence in the successful completion of the process, affecting the flow of resources between the projects. This fundamental difference ultimately seems to have determined the different outcome of the two projects.

What emerges from our study is also a representation of risk taking in entrepreneurial innovation that differs from what seems to be largely accepted in the literature. Most research on risk taking (e.g. Simon, Houghton and Aquino, 1999; Forlani and Mullins, 2000; Simon, Houghton and Savelli, 2003) seems to implicitly conceptualize (and study) risk taking as a one-time decision. Evidence from our study, instead suggests a view of risk taking as an ongoing process subject to periodic revision. While Mr. Guzzoletti initially committed parts of his resources to both projects, his decisions were later revised following the flow of events and his personal assessment of the situation. Past research on risk taking (e.g. Sitkin and Pablo, 1992) has observed a positive relationship between past experience and risk perception. The adoption of a longitudinal perspective brought to the surface the relationships between risk taking and the current flow of experience, and helped us capture the connections between escalating commitment to a course of action and the underlying sensemaking process.

Finally, our findings may increase our understanding of the relationships between human capital and entrepreneurial activity. A recent study of Swedish nascent entrepreneurs (Davidsson and Honig, 2003) observed how formal education positively affects opportunity recognition but cannot significantly discriminate between successful and unsuccessful entrepreneurial process. In other words, previously held knowledge did not significantly affect the successful completion of entrepreneurial projects. Insights from our study suggest that these results may be affected by a discrepancy between formal education and the actual requirements of the projects. In fact, while prior knowledge about the lighting industry helped Mr. Guzzoletti identify the plastic cable as a valuable business opportunity, lack of competence about optics and chemistry may have eventually led to the unsuccessful termination of the project. In this respect, evidence from our study suggests that the relationships between formal education and the successful completion of entrepreneurial projects may be mediated by the congruence between previously held knowledge and the specific requirements of the project. Future research may benefit from more refined measurement of educational background of entrepreneurs and the characteristics of the undertaken projects.

Our findings may have also important implications for the practice of entrepreneurship. Past research indicates that the entrepreneurs' knowledge base may affect their capacity to recognize valuable opportunities (Shane, 2000; Simon, Houghton and Savelli, 2003). Our findings suggest that prior related knowledge may also affect the capacity to evaluate and exploit an opportunity and to develop an idea into a fully-fledged new product or service. Indeed, the experience of Futureplast shows the importance of mastering the technological platforms on which the development of new products rests. In the absence of a related knowledge base, entrepreneurs may be forced to rely on outside assistance for the evaluation of the opportunity, and eventually to abdicate their leading role in the development process, gradually losing the capacity to assess the levels of risk and return associated to the completion of the project. In sum, our findings seem to discourage from initiating explorative venture whose technological platforms are distant from the entrepreneurs' core technological and scientific domains.

Finally, we believe that our findings may be applied even to the broader case of corporate venturing, as they may improve our understanding of the implications of managing multiple development projects. A dominant framework in the field of corporate venturing contends that technology development within organizations is the result of the interplay of partly autonomous and partly induced development initiatives that compete for limited resources (Burgelman, 1991). The results of this competition depend on how attention, resources and rewards are channeled through the organizational context, and on how initiatives are selected through the determination of the strategic context (Burgelman, 1991). In this respect, our model may increase our understanding of the cognitive mechanisms that affect patterns of success and failure as a consequence of resource allocation between different corporate ventures (see Van de Ven and Polley, 1992; Garud and Van de Ven, 1992).

In conclusion, we are aware that our findings address only one of the fundamental requirements of successful technology development- i.e. an adequate supply of resources and support to the project. Further research will be required to shed more light on what actors really do with these resources that influences the effectiveness of the project. Furthermore, our study only marginally addresses the issues raised by the collective nature of entrepreneurial learning. Future work may investigate in more depth the factors that affect the capacity of entrepreneurs to harness external knowledge-based contributions during the innovation process and to retain most of the benefits of the newly created knowledge.

References

Agndal, H., 1999. Individual learning among entrepreneurs – Towards a research agenda. In C. Salvato, P. Davidsson, A. Persson (Eds.), Entrepreneurial Knowledge and Learning. Conceptual Advances and Direction for Future Research. JIBS Research Report.

Aldrich, H., Zimmer, C., 1986. Entrepreneurship through social networks. In D. L. Sexton and R. W. Smilor (Eds.), The Art and Science of Entrepreneurship. Cambridge, MA: Ballinger.

Ariño, A., de la Torre, J., 1998. Learning from failure: Towards an evolutionary model of collaborative ventures. Organ. Sc. 9 (3), 306.325.

Bailey, J. B., 1986. Learning styles of successful entrepreneurs. Frontiers of Entrepreneurship Research, Wellesley, MA: Babson College.

Baron, R. A., 1998. Cognitive mechanisms in entrepreneurship: Why and when entrepreneurs think differently than other people. J. Bus. Venturing 13 (4), 275-294.

Bateman, T. S., Zeithaml, C. P., 1989. The psychological context of strategic decisions: a model and convergent findings. Strategic Manag. J., 10, 59-74.

Begley, T., Boyd, D., 1987. Psychological characteristics associated with performance in entrepreneurial firms and small businesses. J. Bus. Venturing, 2, 79-93.

Birley, S., 1985. The role of networks in the entrepreneurial process. J. Bus. Venturing 1, 107-117.

Block, Z., MacMillan, I. C., 1993. Corporate Venturing: Creating New Business Within the Firm. Boston, MA: Harvard Business School Press.

Bower, J. L., 1970. Managing the Resource Allocation Process. Boston, MA: Harvard Business School Press.

Brockhaus, R., 1980. Risk-taking propensity of entrepreneurs. Acad. of Manage. J. 23 (3), 509-520.

Brockhaus, R., Horowitz, P., 1986. The psychology of the entrepreneur. In D. Sexton and R. Smilor (Eds.) The Art and Science of Entrepreneurship. Cambridge, MA: Ballinger.

Brown, S. L., Eisenhardt, K. M., 1997. The art of continuous change: Linking complexity theory and time-paced evolution in relentlessly shifting organizations. Adm. Sc. Q. 42, 1-34.

Burgelman, R. A., 1991. Intraorganizational ecology of strategy making and organizational adaptation: Theory and field research. Organ. Sc. 2, 239-262.

Busenitz, L. A., Barney, J. B., 1997. Differences between entrepreneurs and managers in large organizations: Biases and heuristics in strategic decision-making. J. Bus. Venturing, 12, 9-30.

Carland, J. C., Boulton, F. H., Carland, J. A. C., 1984. Differentiating entrepreneurs from small business owners: A conceptualization. Acad. Manage. Rev. 9(2), 354-359.

Clark, K. B., 1985. The interaction of design hierarchies and market concepts in technological evolution. Res. Pol. 14, 235-251.

Cohen W., Levinthal D., 1990. Absorptive capacity: A new perspective on learning and innovation. Admin. Sc. Q. 35, 128-152.

Cyert, R. M., March, J. G., 1963. A Behavioral Theory of The Firm. Englewood Cliffs, NJ: Prentice Hall.

Davidsson, P., Honig, B., 2003. The role of social and human capital among nascent entrepreneurs. J. Bus. Venturing 18, 301-331.

Dubini, P., Aldrich, H., 1991. Personal and extended networks are central to the entrepreneurial process. J. Bus. Venturing 6, 305-313.

Eisenhardt, K., 1989. Building theories from case studies research. Acad. Manage. Rev. 14, 532-550.

Eisenhardt, K. M., Tabrizi, B. N., 1995. Accelerating adaptive processes:

Product innovation in the global computer industry. Admin. Sc. Q. 40, 84-110.
Fiol, M. C., Lyles, M. A., 1985. Organizational Learning. Acad. of Manage. Rev. 10, 803-813.
Forlani, D., Mullins, J. W., 2000. Perceived risks and choices in entrepreneurs' new venture decisions. J. Bus. Venturing 15, 305-322.
Friedlander, F., 1983. Patterns of individual and organizational learning. In Srivastava S. and associates (Eds.) The Executive Mind: New Insights on Managerial Thought and Action. San Francisco, CA: Jossey-Bass.
Garnsey, E., 1998. A theory of the early growth of the firm. Ind. Corp. Change 13 (3), 523-556.
Gartner, W. B., Birley, S., 2002, Introduction to the special issue on qualitative methods in entrepreneurship research. J. Bus. Venturing 17, 387-395.
Garud, R., Van de Ven, A. H., 1992. An empirical evaluation of the internal corporate venturing process. Strategic Manag. J. 13, 93-109.
Gifford, S., 1998. The Allocation of Limited Entrepreneurial Attention. Boston, MA: Kluwer Academic Publishers
Glaser, B., Strauss, A., 1967. The Discovery of Grounded Theory: Strategies for Qualitative Research. Chicago, IL: Aldine.
Glassman, R.B., 1973. Persistence and loose coupling in living systems. Behav. Sc., 18.
Guth, W., Kumaraswamy, A., McErlen, M., 1991. Cognition, enactment and learning in the entrepreneurial process. Frontiers of Entrepreneurship Research, Wellesley, MA: Babson College.
Hayek, F. von, 1945. The use of knowledge in society. Am. Ec. Rev. 35, 519-530.
Ireland, R.D., Hitt, M.A., Camp, S.M., Sexton, D.L., 2001. Integrating entrepreneurship and strategic management actions to create firm wealth. Acad. Manag. Exec. 15 (1), 49-63.
Kahneman, D., Lovallo, D., 1993. Timid choices and bold forecasts: A cognitive perspective on risk taking. Manag. Sc., 39 (1), 17-31.
Kirchoff, B. A., 1994. Entrepreneurship and Dynamic Capitalism. Westport: Praeger.
Kirzner, I., 1973. Competition and Entrepreneurship. Chicago, IL: University of Chicago Press.
Kirzner, I., 1977. Entrepreneurial discovery and the competitive market process: An Austrian approach. J. Ec. Lit., 35, 60-85.
Langley, A., 1999. Strategies for theorizing from process data. Acad. Manag. Rev. 24, 691-710.
Larson, A., 1991. Partner networks: Leveraging external ties to improve entrepreneurial performance. J. Bus. Vent. 6(3), 173-188.
Lee, T. W., 1999. Using Qualitative Methods in Organization Research. Thousand Oaks, CA: Sage.
Leonard-Barton, D., 1992. Core capabilities and core rigidities: A paradox in managing new product development. Strategic Manag. J. 13, 111-125.
Levinthal, D. A., March, J. G., 1981. A model of adaptive organizational search. J. Ec. Behav. Organ. 2, 307-333.
Low, M. B., MacMillan, I. C., 1988. Entrepreneurship: Past research and future challenges. J. Manag. 14 (2), 139-161.
March, J. G., 1991. Exploration and exploitation in organizational learning. Organ. Sc. 2 (1), 71-87.
March, J.G., Olsen, J.P., 1976. Ambiguity and Choice in Organizations. Bergen: Universitetsforlaget.
McClelland, D., 1961. The Achieving Society. Princeton, NJ: D. Van Nostrand
McGrath, R., 1995. Advantage from adversity: Learning from disappointment in internal corporate venturing. J. Bus. Venturing 10 (2), 121-142.
Miles, M., Huberman, A., 1984. Qualitative Data Analysis. Beverly Hills, CA:

Sage.
Miner, A. S., Mezias, S. J., 1996. Ugly duckling no more: Pasts and futures of organizational learning research. Organ. Sc. 7, 88-99.
Minniti, M., Bygrave, W., 2001. A dynamic model of entrepreneurial learning. Entrepreneurship Theory Practice 25(3), 5-16.
Nelson R., Winter S., 1982. An Evolutionary Theory of Economics Change. Cambridge, MA: Harvard University Press.
Nicholls-Nixon, C. L., Cooper, A. C., Woo, C. Y., 2000. Strategic experimentation: Understanding change and performance in new ventures. J. of Bus. Venturing 15, 493-521.
Orton, J.D., Weick, K.E., 1988. Toward a theory of the loosely coupled systems. W.P. No. 586, University of Michigan, School of Business Administration, Ann Arbor, MI.
Palich, L., Bagby, R., 1995. Using cognitive theory to explain entrepreneurial risk-taking: Challenging the conventional wisdom. J. Bus. Venturing 10 (6), 425-438.
Pelz, D. C., Andrews, F. M., 1966. Scientists in Organizations. New York, NJ: Wiley.
Polany M., 1966. The Tacit Dimension. London, UK: Routledge and Kegan Paul.
Powell W. W., Koput K. W., Smith-Doerr L., 1996. Interorganizational collaboration and the locus of innovation: Networks of learning in biotechnology. Admin. Sc. Q. 41, 116-145.
Reed, R., DeFilippi, R. J., 1990. Causal ambiguity, barriers to imitation, and sustainable competitive advantage. Acad. Manag. Rev. 15, 88-117.
Schumpeter, J. A., 1936. The Theory of Economic Development (Second edition). Cambridge, MA: Harvard University Press.
Shane, S., 2000. Prior knowledge and the discovery of entrepreneurial opportunities. Organ. Sc. 11, 448-469.
Shane, S., Venkataraman S., 2000. The promise of entrepreneurship as a field of research. Acad. of Manag. Rev. 25 (1), 217-226.
Shaver, K.G., Scott, L.R., 1991. Person, process, choice: The psychology of new venture creation. Entrepreneurship Theory Practice 15, 23-42 (Winter).
Simon, H., 1996. The Sciences of the Artificial. Cambridge, MA: The MIT Press.
Simon, M., Houghton, S. M., Aquino, K., 1999. Cognitive biases, risk perception, and venture formation: How individuals decide to start companies. J. Bus. Venturing 15, 113-134.
Simon, M., Houghton, S. M., Savelli, S., 2003. Out of the frying pan…? Why small business managers introduce high-risk products. J. of Bus. Venturing 18, 419-440.
Sitkin, S. B., Pablo, A. L., 1992. Reconceptualizing the determinants of risk behavior. Acad. Manag. Rev. 1, 9-38.
Staw, B. M., 1976. Knee-deep in the big muddy: a study of escalating commitment to a chose course of action. Organ. Behav. Human Performance 16, 27-44.
Staw, B. M., Ross, J., 1978 Commitment to a policy decision: a multi-theoretical perspective. Admin. Sc. Q. 23, 40-64.
Staw, B., Fox, F., 1977. Escalation: some determinants of commitment to a previously chosen course of action. Human Rel. 30, 431-450.
Stevenson, H. H., Gumpert., 1985. The heart of entrepreneurship. Harvard Bus. Rev. 85 (2), 85-94.
Szulanski, G., 1996. Exploring internal stickiness: Impediments to the transfer of best practice within the firm. Strategic Man. J. 17, 27-43.
Tversky, A., Kahneman, D., 1986. Rational choice and the framing of decisions. J. of Bus. 59 (4), 251-278.
Van de Ven, A. H., Polley, D., 1992. Learning while innovating. Organ. Sc. 3, 92-116
Van de Ven, A. H., Venkatraman S., Polley D., Garud. R., 1989. Processes of new

business creation in different organizational settings.” In A. H. Van de Ven, H Angle, and M. S. Poole (Eds.) Research on the Management of Innovation. New York, NJ: Ballinger Press.

Weick, K., 1995. Sensemaking in Organizations. Thousand Oaks, CA: Sage Publications

Weick, K. E., 1979. The Social Psychology of Organizing. Reading, MA: Addison Wesley.

Woyceshin, J., 2000. Technology adoption: Organizational learning in oil firms. Organ. Stud. 21(6), 1095-1118.

Yin, R. K., 1989. Case Study Research: Design and Methods. Newbury Park, CA: Sage.

Figure 1. The chronology of the two processes

Time		Project 1	Project 2	Data collection
1996	Feb			
	Mar	Mr. Guzzoletti visits a trade fair in Munich		
	Apr	Mr. Guzzoletti hires Mr. Monteverdi		
	May			
	Jun		Research on laser shows	
	Jul			
	Aug	Research on plastic cable		
	Sep		Mr. Guzzoletti visits a fair in Moscow	
	Oct			
	Nov	Search for a partner	Mr. Guzzoletti meets Mr. Nava	
	Dec			
1997	Jan			
	Feb			First round of interviews
	Mar			
	Apr	Preliminary tests (CNR)		
	May			
	Jun			
	Jul			
	Aug	Termination of the project		
	Sep			
	Oct			
	Nov			
	Dec		Renewal of the contract with CISE	
1998	Jan			Second round of interviews
	Feb			
	Mar			
	Apr			
	May			
	Jun			
	Jul			
	Aug			
	Sep			
	Oct		Functioning prototype is ready	
	Nov			Feed back on emerging Framework
	Dec			

Table 1. Conditions of success and failure in the observed development processes

PLASTIC CABLE (unsuccessful)	Laser system (successful)
HIGHER CAUSAL INDETERMINACY Lower structuration of the problem Task: reproducing a new material starting from a sample	LOWER CAUSAL INDETERMINACY Higher structuration of the problem Task: integrating different component technologies
LACK OF RELATED KNOWLEDGE Lack of the required scientific knowledge base (optic, chemistry) Few external sources of knowledge (patents) Little time dedicated to knowledge acquisition (optical fibers, light conduction)	POSSESSION OF RELATED KNOWLEDGE Extensive review of existing licenses Much time dedicated to the acquisition of the fundamental knowledge basis (physics, laser technology)
LOW CONTROL OF THE PROCESS Research is conducted by an external research lab (CNR) Occasional visits to the research site	HIGH CONTROL OF THE PROCESS Research is conducted in in-house laboratories Continuous participation to the research and development process; systematic "reverse engineering"
INCREASINGLY UNCERTAIN PERCEPTION OF RETURN No material incentive for CNR Commercial application is uncertain and distant in time	INCREASING CONFIDENCE IN COMMERCIAL RETURN Key actors share a specific interest and a commercial incentive Potential applications get clearer overtime

Figure 2. Entrepreneurial innovation as a self-reinforcing learning process

-

Commitment (time, attention and resources)

Perceived uncertainty of return

-

+ Causal indeterminacy -

- -

Related knowledge base

Control of the process

+

----

[1] This paper has been written thanks to the financial support of the UE, research project "Small Business Training and Competitiveness: Building case studies in different European cultural contexts". We thank Paola Dubini, Morten Huse, Bengt Johannisson, Carlo Salvato and

Harry Sapienza for their helpful comments on earlier versions of this paper.